A DIS-COMPLIANT MODEL FOR ESTIMATING CHEMICAL AND BIOLOGICAL WEAPONS EFFECTS ON THE VIRTUAL BATTLEFIELD

Dr. Julius Lilly
U S Army Space and Strategic Defense Command
P.O. Box 1500, 106 Wynn Drive
Huntsville, Alabama 35807
lillyj@ssdch-usassdc.mil

Bill Moore
MEVATEC Corporation
1525 Perimeter Parkway, Suite 500
Huntsville, Alabama 35806
bill_moore@mevatec.com

19970912 141

Abstract

The United States Army Space and Strategic Defense Command has begun integration of dirty battlefield effects into the Synthetic Battlefield Environment (SBE). The SBE is a battlefield virtual emulation and visulization tool used by the Space and Missile Defense BattleLab in Huntsville Alabama. The SBE allows a battlefield scenario to be played with realtime models and visulization via "Gods Eye View". The SBE currently models detonation of theater ballistic missiles (TBM) carrying high explosive payloads. TBMs, however, carry a variety of payload types: high explosive, chemical/biological weapons or nuclear. The payloads may be configured to carry unitary or submunition weapons. These TBM payloads whether offensively deployed or intercepted effect the battlefield atmosphere and ground environments. These dirty battlefield effects reduce unit effectiveness by causing casualties, damaging equipment, rerouting personnel and equipment, degrading sensor performance, putting personnel into Mission Oriented Protection Posture, and requiring decontamination procedures. In summary, a realistic battlefield scenario is only provided through integration of all these effects.

Introduction

A hit is not necessarily a kill in missile defense. During the Gulf war, theater ballistic missiles (TBMs) carrying unitary high explosive (HE) payloads were intercepted by air defense batteries. Not all of these intercepts were successful hits. Some warheads missed the targeted TBM, while others hit the missile but missed the payload section. The results were the same; the surviving TBM detonated upon impact with the ground. These same TBMs could have been launched with unitary chemical payloads during the war, but were not. It is perhaps more important to evaluate tactical misses than perfect intercepts (kills).

Simulations were used in the Gulf war to evaluate potential theater missile defense scenarios. The ground effects of TBMs carrying unitary chemical payloads were also assessed. Most computer models limit their missile defense simulations to TBMs and cruise missiles (CM) trajectories and their intercept. The probability-of-hit suffices to determine if the intercept was successful (probability of kill). These simulations usually include unitary high explosive (HE) payloads detonating upon impact with the ground. Two important aspects of these battlefields are not simulated: threat payload variations and post-engagement effects. These common limitations do not allow realistic battlefield environment simulation.

The U.S. Army Space and Strategic Defense Command (USASSDC) has enhanced its synthetic battlefield environment (SBE) simulation capability by incorporating the Post-Engagement Ground Effects Model (PEGEM) into the SBE through DIS compliance. PEGEM provides chemical/biological warfare (CBW), HE effects, debris characterization (currently being modeled).

Dirty Battlefield Effects

TBMs and CMs can carry a variety of payload types such as HE, CBW agents, or nuclear weapons. The payload configurations include unitary and submunitions. Submunitions may vary in size and shape (canister, rectangular, spherical) depending on their offensive deployment scheme. Each payload type affects the battlefield differently, depending on the TBM offensive deployment scheme or, if intercepted, the engagement conditions.

Dirty battlefield effects, as related to theater missile defense, cover a wide range of phenomenology, both in the atmosphere and on the surface (Figure 1). These

This paper has been cleared for unlimited distribution by the U.S. Army Space and Missile Defense Command on 8/6/97

DTIC QUALITY INSPECTED 2

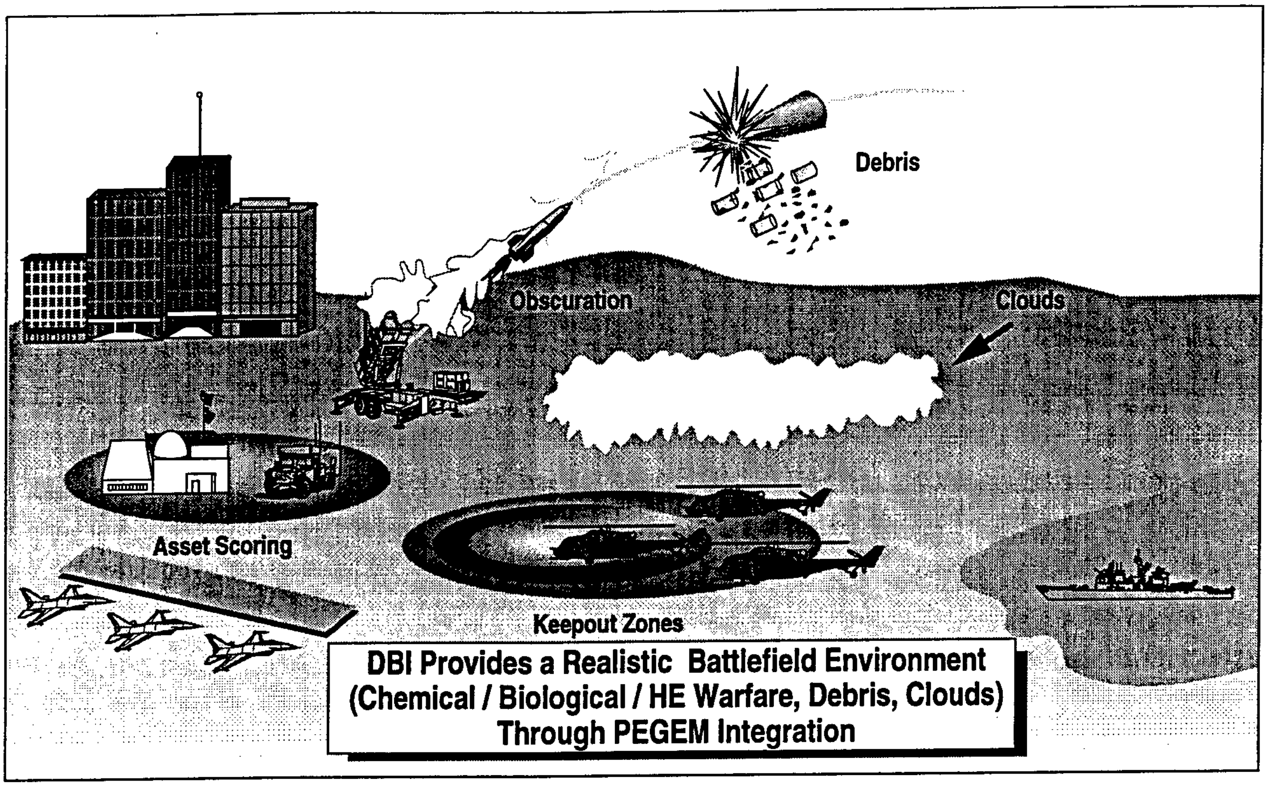

Figure 1 Dirty Battlefield Enhancements to SBE

effects alter the battlefield environment, and therefore, the direction of the battle. These effects will be discussed individually in the sections to follow.

A successful intercept of a TBM results in interceptor and threat debris falling to the ground. These debris clouds contain fragments that vary in size, shape, and material. At high closing velocities, the debris fields are independent of each other; but at low closing velocities, they interact. Some debris is large enough or the cloud is dense enough for sensors to track, thereby increasing the number of objects observed and possibly masking incoming threats. At ground impact, the debris may cause collateral damage (i.e., casualties or equipment damage). For CBW payloads, the threat debris may be contaminated with the agent.

Unitary HE effects are used extensively in many battlefield simulations. If a unitary threat is intercepted and the payload is hit then, as seen in the Gulf war, a large flash occurs and debris falls to the ground. However, if the payload is missed, the TBMs with a slightly perturbed trajectory detonate on impact with the ground. For HE submunitions, some may survive intercept. Those surviving can function offensively. The ground impact point, however, will be different than the intended aimpoint because of meteorological (MET) conditions and intercept location, possibly landing near or on other ground assets.

When CBW agents are involved, the battlefield can be affected in several ways. CBW agents take many forms: thickened or unthickened, persistent or non-persistent, inhalation or percutaneous entry, liquid or dry slurry, along with being blister, nerve, toxins, etc. Contamination duration is affected by agent persistence, MET conditions, time of day, volitility, biological decay rates, and chemical agent reaction rates. Unit effectiveness decreases under threat of CBW as personnel and equipment function under conditions often including the use of Mission Oriented Protection Posture (MOPP) gear. Identification and warning of CBW agents requires nuclear, biological, and chemical (NBC) sensors. These sensors must be positioned such that agents are detected and recognized, so first warning may occur when personnel or equipment are affected.

Unitary CBW payloads may deploy their payload at a predetermined altitude or upon impact with the ground. Atmospheric release is usually relegated to persistent thickened chemical agents. These agents are only partially destroyed when intercepted, presenting a hazard in the air and on the ground. This surviving airborne chemical cloud can also attenuate sensor signals. The

larger droplets fall to the ground in minutes even from high altitude intercepts, while the smaller droplets take hours to reach the ground, if at all. The ground contamination zone location, size, and concentration depends on the MET conditions and the release point (intercept or offensive). Ground contamination zones are shifted away from the aimpoint and increase in size as a result of intercept but contain lower, less lethal, concentration levels. A shifted contamination zone may affect other ground/air assets. Ground contamination from persistent agents may last hours or days depending on terrain and climate.

Submunitions can be difficult to destroy at intercept. Surviving submunitions are shifted away from their intended aimpoint, possibly threatening other ground assets. Intact submunitions may function as intended upon impact with the ground. For chemical submunition agents, small contamination zones of agent are formed that can overlap by design to form larger, more lethal contamination zones. For biological submunition agents, a single massive overlapping contamination zone is formed due to the higher number of biological submunitions in a typical payload. If intercepted, this ground contamination zone may be more dangerous than the smaller contamination zone due to the high toxicity of biological agents.

NWE may be classified as prompt or long term. Prompt effects include blast, thermal, and near term radiation that may incapacitate/kill personnel or assets within a short period of time. Long term effects result from exposure to fallout, lower levels of radiation, burn areas, etc.

PEGEM

The Post-Engagement Ground Effects Model (PEGEM) is a comprehensive simulation tool that provides ground hazard assessment for CBW release and HE weapons. Model output includes chemical/biological agent ground contamination, HE blast/fragmentation zones, data for unit effectiveness or many-on-many models, as well as estimated casualties at user-specified times-of-interest. PEGEM encompases a number of modeling areas in order to assess ground effects from unitary (bulk) and submunition (canister or bomblet) payload intercepts and offensive deployments.

PEGEM is an integration of several previously existing models, as well as models developed for this application. Figure 2 illustrates the PEGEM architecture and external interfaces. Payload and agent type require specific combinations of algorithms to accurately model ground effects. In a typical case, the analyst specifies a chemical or biological weapon event

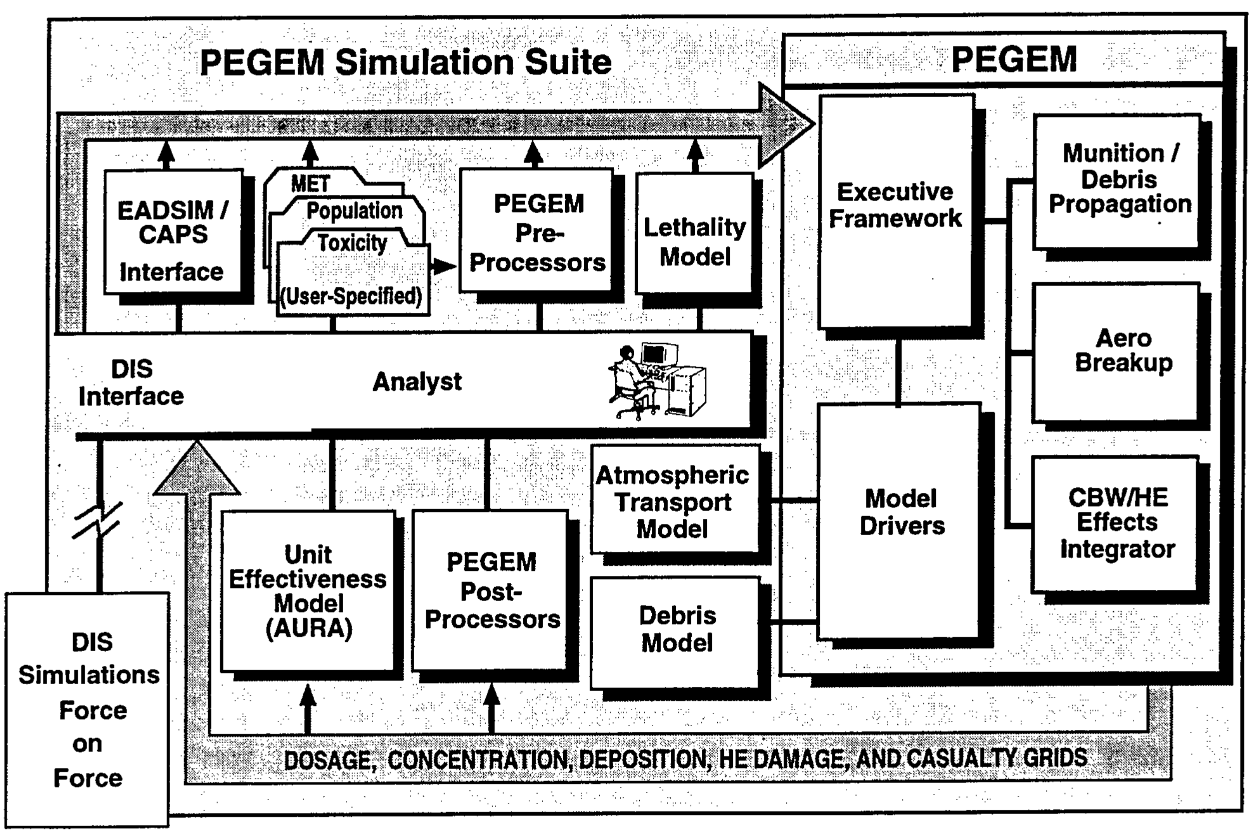

Figure 2 PEGEM Architecture and External Interfaces

scenario or combination, including all threat details and the locations and times of the various events on the user-defined grid. Intercept lethality information can be provided through the output of an endgame lethality model such as PEELS. The lethality model provides PEGEM with a prediction of the fraction of payload agent or submunitions surviving following an intercept event. For canister submunition payloads, the location of surviving submunitions within the target payload is given. This information is used by PEGEM to propagate the potential residual threat(s) to the ground.

Given the intercept lethality data from the engagement for submunition payloads, PEGEM determines the ejection velocity vectors of surviving submunitions using a semi-empirical methodology validated by sled tests. This methodology is derived from relationships between endgame characteristics and ejection velocities established through review of results from high speed impact sled tests, quarter-scale light-gas gun tests, and hydrocode analyses. Once initial velocity vectors are determined, submunitions are propagated to the ground using a three degree-of-freedom (3-DOF) model with averaged tumbling munition drag data. Some munitions with more complex flight characteristics require a six degree-of-freedom (6-DOF) model. With either flyout approach, wind effects on submunition propagation are included. MET data are provided to PEGEM through a stratified atmosphere model that provides wind velocity as a function of altitude along with pertinent atmospheric parameters as a function of time. A MET profile can be specified at multiple times during a scenario to simulate operational battlefield environments. MET data is linearly interpolated by PEGEM for flyout calculations of munitions.

In contrast to submunition payloads, unitary (bulk) chemical payload analyses require the PEGEM Aerodynamic Breakup Model to characterize the initial chemical agent source cloud that results from a unitary threat intercept, or an unintercepted / normal release into the atmosphere. This model determines chemical agent line source length, lateral dimension, removes in situ losses, accounts for aerosolization (losses due to atmospheric interaction), and agent droplet size distribution as a function of release conditions. This empirically based approach is derived from extensive agent simulant testing results.

Once the initial source cloud is described, the Vapor, Liquid, and Solid Tracking (VLSTRACK) model, an atmospheric transport and diffusion model (Bauer 1995), determines ground deposition, dosage, and concentration from a unitary chemical release. This model calculates the transport, evaporation, and diffusion of tri-variate Gaussian puff clouds of liquid, vapor, and in some cases, solids. Since PEGEM casualty calculations are based on short-term cumulative rather than instantaneous contamination levels, the atmospheric transport model is run in a cumulative mode also. As with the previously described flyout models, the atmospheric transport model uses interpolated MET data in performing transport calculations. Atmospheric transport model output is in the form of deposition, dosage, cloud size sigmas at user-specified intervals, and concentrations. Deposition is a measure of contamination area coverage typically measured in milligrams of agent per square meter. Concentration is a volumetric measure of agent contamination measured in milligrams per cubic meter, usually at a specified height above the ground (~2 m for personnel effects) throughout an area. Dosage is the time integral of concentration, taking into account not just level of exposure, but time exposure as well. Dosage is typically given in units of milligram-minutes per cubic meter. Cloud size sigmas are expressed in terms of horizontal, vertical, and lateral sigmas. When biological agents are involved the unit of mass in the above measurements typically changes from milligrams to micrograms.

Once ground deposition, dosage, and concentration for all threats in a scenario are determined, the final steps in the simulation are to produce contamination grids and calculate casualties. The PEGEM Effects Integrator Model convolves atmospheric transport model contamination grids, discrete population data, and probit methodologies for assessing toxicity effects to produce casualty estimates. This approach for estimating casualties uses a standard probit-based methodology originally proposed by D. J. Finney (Finney 1971) for probabilistically determining response to a pathogen. This approach requires that response data be available in order to determine a median lethal effective dosage or deposition value for the agent in question, along with the probit-response slope which describes the rate of change of effectiveness as dosage or deposition levels change. This toxicity data is often derived from extensive tests on mammals including, in some cases, humans. Chemical agent toxicity data employed by PEGEM are derived from a recent Army toxicity standard report (Reutter 1994). Similar standards are currently being compiled for agents of biological origin (ABO).

Chemical/biological submunition payloads also require the use of the atmospheric transport and hazard assessment model. Once the ground impact points of

submunitions have been determined using the appropriate flyout model, munitions are assumed to undergo normal (usually ground level) agent release. The initial source cloud release points are provided by PEGEM and the resulting ground deposition, dosage, and concentration are determined by VLSTRACK. Cloud size sigmas are not furnished for submunition generated agent clouds because they begin as a point source.

HE payloads are handled in a manner similar to established CBWs. Offensively deployed unitary HE payloads detonate on or near the ground while those unitary HE payloads that are successfully intercepted are destroyed. However, HE submunitions may survive an intercept. Surviving HE submunitions are handled similarly to chemical/biological submunitions. The location of surviving submunitions within the target payload must be provided by a lethality model. This information is used by PEGEM to propagate the potential residual live submunitions to the ground using either a 3-DOF or 6-DOF model. HE munitions require the use of blast and fragmentation (under development) models to comprehensively model HE detonation at or just above the ground (Church 1995). Blast and fragmentation zones are then determined.

Once the ground blast/fragmentation zones are determined, the final steps in simulating the battlefield environment are to produce blast/fragmentation grids and calculate casualties similar to the chemical and biological agent methodology. Blast/fragmentation grids, discrete population data, and probit methodologies for assessing blast effects are convolved to determine casualty estimates. The approach for estimating casualties is a standard probit-based methodology (Richmond 1966) for probabilistically determining response to a pressure wave. This approach requires that response data be available in order to determine a median lethal effective pressure value for the HE agent in question, along with the probit-response slope which describes the rate of change of effectiveness as pressure changes. Casualty estimation from fragmentation is to be based on fragment density and kinetic energy.

Debris model integration into PEGEM, currently under development, will rely on an existing debris model. Large debris will be deterministically propagated to the ground. Ground personnel or equipment near the impact points will be assigned a certain probability of being affected by the debris. The probability of large debris causing collateral effects is very low. However, if enough TBM intercepts occur during a battle, then the cumulative probability of debris causing personnel casualties or equipment damage becomes significant.

Synthetic Battlefield Environment

PEGEM, a Distributive Interactive Simulation (DIS) compliant model, is capable of operating in real time or non-real time. Models, such as the many-on-many simulations, Extended Air Defense Test Bed (EADTB) and Extended Air Defense Simulation (EADSIM), have been connected via DIS to PEGEM. This connectivity has been proven in Army Experiment 3 and tactical operation center training. These models provide data on interceptors, threats, and ground assets to which PEGEM responds whenever an intercept occurs or when a TBM payload is offensively deployed. PEGEM models NBC sensors, broadcasting NBC tactical sensor warning messages along with identifying assets (personnel and equipment) effected by CBW, and contamination cloud locations. PEGEM, when operating in the SBE, currently responds only to CBW since most simulations handle unitary HE on their own. In the future, debris and HE submunitions will be included. Also PEGEM will pass its environmental effects data to other models. It is anticipated that PEGEM will become High Level Architecture (HLA) compliant in the near future.

The inclusion of realistic battlefield effects into the SBE may or may not effect the battle. Because CBW effects last minutes to hours, perhaps days, and sometimes require similar periods of time before the effects manifest themselves, CBW has not normally been included in many-on-many simulations. Recently exercises that last many hours (i.e., FPTOC training over 24 hours) have included dirty battlefield effects.

An example TBM attack scenario, described below, illustrate a plausible dirty battlefield scenario. Two TBMs will be launched (Table 1), a unitary chemical payload targeted for an airbase and a chemical submunition payload targeted at forward deployed troops. The first scenario will be an offensive deployment of both threats, the second will be an intercept of both. The airbase consists of aircraft, a control tower, runways, and support facilities. The forward deployed troops are spread across the front line in foxholes, etc. For this example, the airbase contains aircraft and personnel while the forward deployed troops are not in MOPP gear. A constant 10 km/hr wind is estimated for transport and diffusion purposes, and submunition descent.

In the first case, the payloads deploy offensively, as shown in Table 1. The unitary chemical agent covers

	Unitary Chemical Payload	Chemical Submunition Payload
Agent	Thickened VX (nerve agent)	GB (Sarin)
Fill Weight	500 kg	1 kg
Munitions	1	50
Deployment Altitude	1 km	2 km

Table 1 Threat Characteristics

much of the airbase. Most of the aircraft and ground equipment is contaminated and some of the ground personnel may become casualties. Before the aircraft and equipment can be used, it must be decontaminated, otherwise, more casualties may occur and equipment damage. Personnel reduction contributes to a reduction in airbase effectiveness. During that period of time few air operations are flown. For the forward deployed troops, localized heavy casualties may occur from the agent GB if the troops do not immediately get into MOPP. The agent GB quickly dissipates but during this period of time unit effectiveness is reduced. Debris fields miss all units.

Replaying the same scenario again, but this time with payload intercepts, the relative effectiveness of the intercepts can be seen. It is assumed that payloads are at an altitude of 5 km. Fifty percent of the unitary chemical payload is mitigated by the intercept, while 90 percent of the submunition payload is destroyed. The surviving submunitions are assumed to fall to the ground and function as designed upon impact, a defense conservative approach.

The residual unitary chemical agent dispersed at 5 km reaches the ground two kilometers away from the airbase. Air operations are not affected. However, a supply depot was located in the area of the residual ground contamination. Some of the logistics personnel may become casualties and all uncovered supplies and trucks are contaminated. The supply depot is not operational until chemical decontamination occurs. The five surviving chemical submunitions miss the forward deployed troops. Unit effectiveness is not affected. Debris missed the forward deployed troops but damaged a logistics vehicle near the supply depot.

Thus CBW attacks directly and indirectly affect unit operations. The airbase is inoperable not because of casualties or aircraft destruction, but equipment contamination. Even when the unitary chemical TBM was intercepted, another unit was affected. All units must be rerouted around the ground contamination zone until the persistent agent is neutralized, naturally or by decontamination procedures. The forward deployed troops must have enough warning to get into MOPP gear or they become casualties. A successful intercept of the chemical submunition TBM greatly enhances their survival and unit effectiveness.

Use of dirty battlefield effects requires modification to many simulations. Several issues and approaches must be addressed such as correct TBM doctrine, equipment contamination, MOPP levels for personnel and equipment, rerouting around contamination zones, unit effectiveness, and decontamination procedures.

Conclusion

Models and simulations (M&S) have been used for a number of years to provide needed functional and operational information about systems. Many of these M&S have been developed without commonalities to allow integration and a continuum in modeling the entire battle from end-to-end. The SBE is one of the first steps to furthering the use of M&S. New standards such as DIS and HLA are designed to exploit emerging computer and telecommunications technologies in the growth of the SBE. These standards provide the foundation to develop collaborative models which fulfill the need to model end-to-end battles. PEGEM's chemical/biological, HE, and soon debris ground effects provide dirty battlefield conditions for the SBE through the interoperability of these standards. Dirty battlefield effects, when they occur, may affect the direction of the battle. Planning for these uncertainties is now possible. Indeed, a hit is not necessarily a kill in missile defense.

In the future, additional enhancements to the dirty battlefield should be available such as sensor attenuation and NWE. Both high and low fidelity M&S are now able to incorporate dirty battlefield effects in a seamless manner through distributed simulations, thereby permitting them to not only enhance their environment but expand their capabilities.

References

Bauer, T. 1995. “Software User's Manual for the Chemical/Biological Agent Vapor, Liquid, and Solid Tracking (VLSTRACK) Computer Model Version 1.6,” Naval Surface Warfare Center (February).

Church, H. 1995. "Catalog of Atmospheric Acoustic Prediction Models," Report No. RCC 383-95.

Finney, D. J. 1971. *Probit Analysis*. Cambridge University Press, Cambridge G.B.

Reutter, S., and LTC J. Wade. 1994. "Review of Existing Toxicity Data and Human Estimates for Selected Chemical Agents & Recommended Human Toxicity Estimates Appropriate for Defending the Soldier (U)." Edgewood Research Development & Engineering Center, Edgewood, MD (June).

Richmond, D.R., and E. G. Daman. 1966. "The Relationship Between Selected Blast-Wave Parameters and the Response of Mammals Exposed to Air Blast." Technical Report No. DASA 1860. Lovelace Foundation for Medical Education and Research, Albuquerque, N. M. (November).